



NEXT GENERATION NATURAL GAS VEHICLE PROGRAM

Heavy Duty Rollout: Development of Stoichiometric Natural Gas Engines

**Presented at Clean Cities Conference
Fort Lauderdale, Florida**

Alex Lawson, Stephen Pechkoff
TeleflexGFI Control Systems
May 4 2004





NEXT GENERATION NATURAL GAS VEHICLE PROGRAM

Phase I: Development of a Low NO_x GM 6.0L CNG Engine

Awarded under the DOE/NREL NGNGV Program, and supported by SCAQMD

Objectives

As an adjunct to the production GM T-610 CNG program, develop a low NO_x GM 6.0L CNG medium duty engine which will have NO_x emissions at or below:

- 0.5 g/bhp.hr (0.2 g/bhp.hr as a stretch objective)

Project Team:





PRESENTATION OUTLINE

1. Outline the current Teleflex *GFI*/GM MY 03/04 production launch of the CNG 6.0 L T-610 cargo and passenger vans, and incomplete cab and chassis vehicles up to 12,200 lbs GVWR.
2. Review the NGNGV low NO_x project, which is an adjunct to the GM T-610 production program, to develop advanced emissions control systems for the 6.0 L CNG engine, and has resulted in extremely low emissions for the 6.0 L engine
3. Provide information on a new NGNGV vehicle integration project, involving the same partners, to develop a low NO_x 8.1L heavy duty CNG engine for application and demonstration in truck and low floor bus applications
4. Discuss positioning this CNG low NO_x technology relative to clean diesel applications

TGFI/GM CNG T-610

MY 03/04 PRODUCTION

Four Models Certified in 03 and 04:

- **Complete Box Van – Dedicated CNG**
- **Complete Box Van – Bi-fuel CNG/Gasoline**
- **Incomplete Cutaway Chassis – Dedicated CNG**
- **Incomplete Cutaway Chassis – Bi-fuel CNG/Gasoline**

Specifications:

All vehicles equipped with 6L V8 SI engine, 300 HP on gasoline

Complete box vans 8600lbs and 9600 lbs GVWR, ALVW<8500

Incomplete cutaway 12,200 lbs GVWR

MY 04 Engine Certification Levels GM T610 CNG



MY 04 GM T610 Engine Emission Cert. Results CNG	NMHC + NO _x	CO	HCHO
	0.457 g/hp.hr at useful life	1.14 g/hp.hr at useful life	0.001 g/hp.hr at useful life

CARB g/bhp.hr				EPA g/bhp.hr				
Standard	NMHC+NO _x	CO	HCHO	Standard	NMHC+NO _x	CO	HCHO	
LEV I ULEV	2.5	14.4	0.050	Fed ULEV	2.5	7.2	0.025	
LEV I SULEV	2.0	7.2	0.025					
Fed '04 Option 1	1.5	14.4	0.050	LEV Fed '04 Option 1	1.5	14.4	0.050	Production Gasoline Cert Level
[LEV II] '05 ULEV	1.0	7.2	0.050	ULEV Fed '04 Option 1*	1.0	7.2	0.025	Production CNG Cert Level
[LEV II] 05 SULEV	0.5	7.2	0.025					

Emissions Component	2006	2007	2008	2009	2010	2011
NOx		50% at 0.20 g/hp.hr			100% at 0.20 g/	
NMHC		0.14 g/hp.hr				
PM		100% at 0.01 g/hp.hr				

NGNGV Low NO_x Project



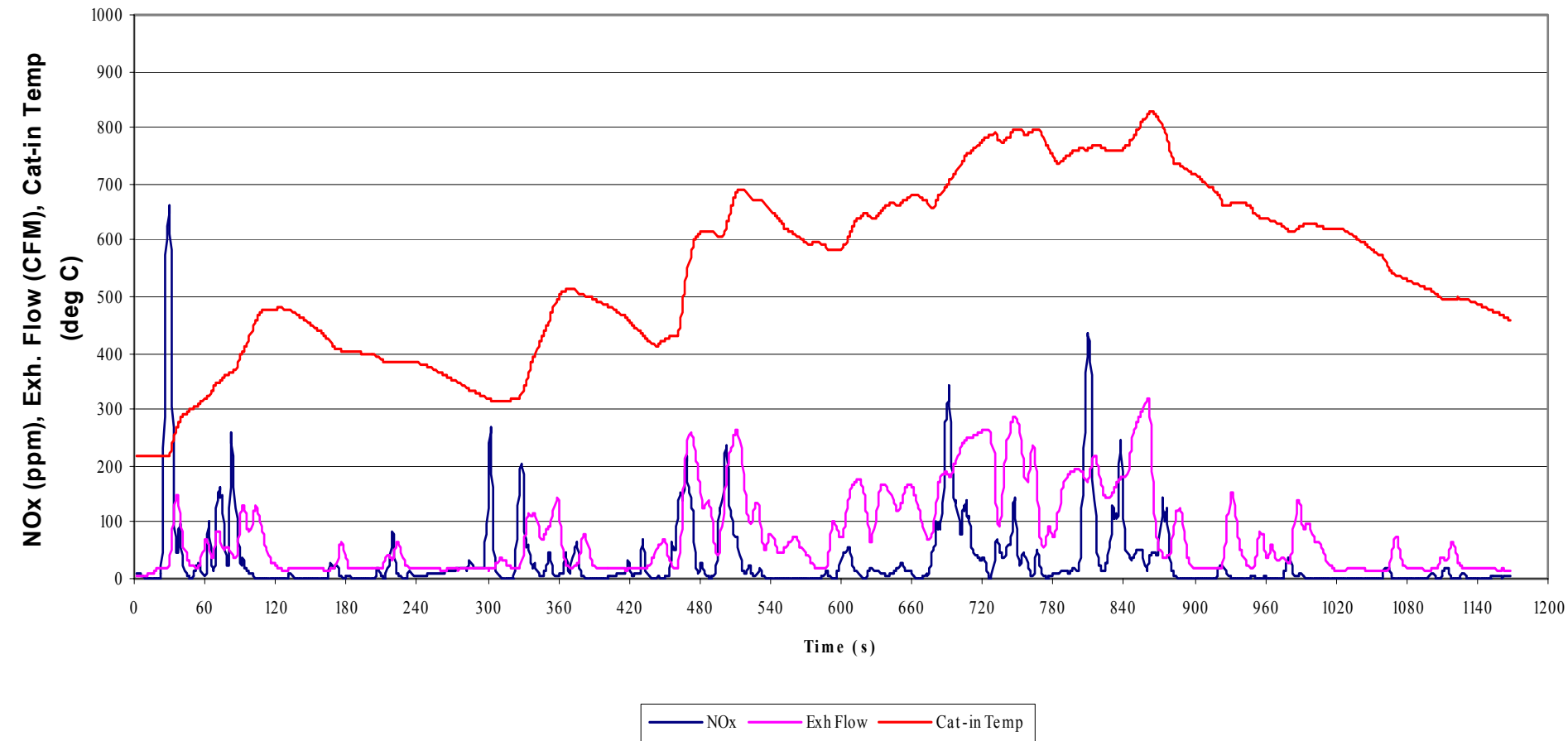
How do we improve emissions performance of the CNG GMT610?

Baseline emissions data collected to determine the advanced catalysts design:

- Transient cycle data, second by second, for emissions components, engine out, cat out, cat temp traces, A/F ratios, exhaust flow rates
- Catalyst efficiency tests, raw emissions over steady state engine conditions, temps, A/F ratios

Hot Transient NOx Response Production Catalysts

Production Cats - Cat-out NOx, Exh. Flow, Cat-in Temp vs Time



Areas where Emissions Improvement can be Achieved



Two major area of NO_x breakthrough determined where emissions improvement can be achieved:

- Cold transient NO_x spike, caused by insufficient temperature
- Cold transient NO_x breakthrough caused by high exhaust flow rates. Insufficient residence time at this point in the cycle

Low Emissions Result from a Combination of Advanced Engine Technologies and Advanced Emission Control Technologies



Advanced Emission Control Technologies include:

- **Advanced thermally stable, oxygen storage materials**
- **In many cases, layered TWC coating architectures**
- **In some cases, HC adsorber functions**
- **High cell density substrates**
- **Fast response oxygen sensors**
- **Thermal management hardware including air-gap pipes & low heat capacity manifolds**

Advanced Engine Technologies include:

- **Improved fuel injectors**
- **Variable valve technology**
- **Lean start strategy with spark retard for fast catalyst heat-up**
- **Electrically controlled EGR valve**
- **Advanced control algorithms for precise A/F control**

Strategies for Advanced Catalyst Design

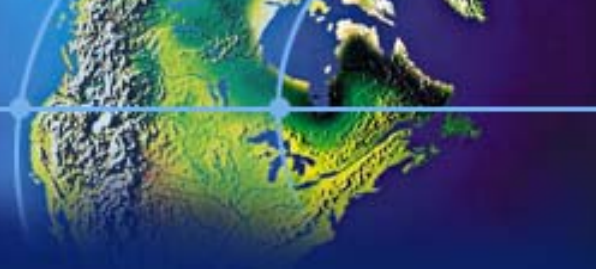


Advanced Catalyst Options:

- Substrate cell density change – U/F cats – enhanced residence time
- Washcoat technology upgrade – trimetal with low and high Pd – enhanced low temperature performance
- Move existing package closer – enhanced low temperature performance
- Close coupled plus U/F cats, with upgraded substrate cell density change
- Calibration options

Advanced Catalysts

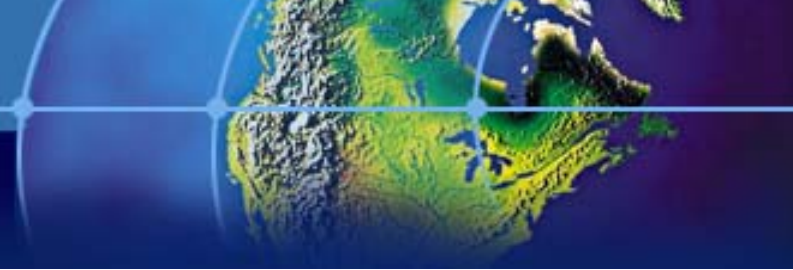
Selected for test program



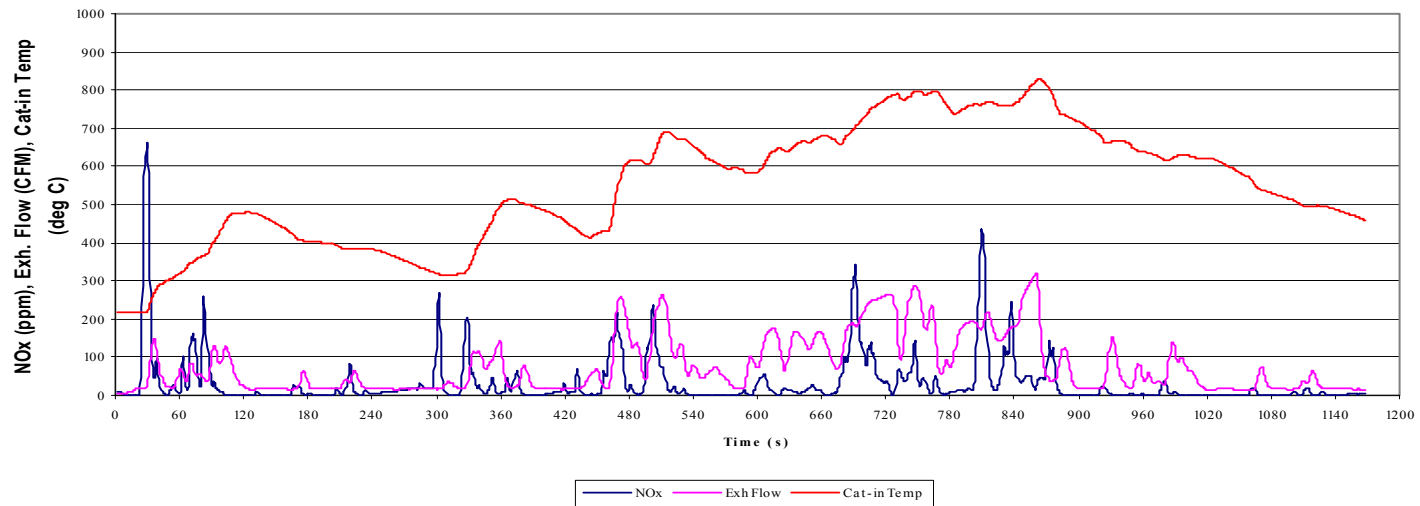
Advanced Catalysts Selected:

- Huntsville, Alabama facility –
600 cpsi/3.5 mil wall NEX 311H1 catalyst technology with
30 g/ft³ Pt/Pd/Rh 3/0/1 (current cats 350 cpsi/5.5 mil wall)
- Nienburg, Germany facility –
600 cpsi/3.5 mil wall OEX-101B catalyst technology with
30 g/ft³ Pt/Pd/Rh 1/2/1
- 600 cpsi/3.5 mil wall OEX-101B with 45 g/ft³ Pt/Pd/Rh
1/2/1

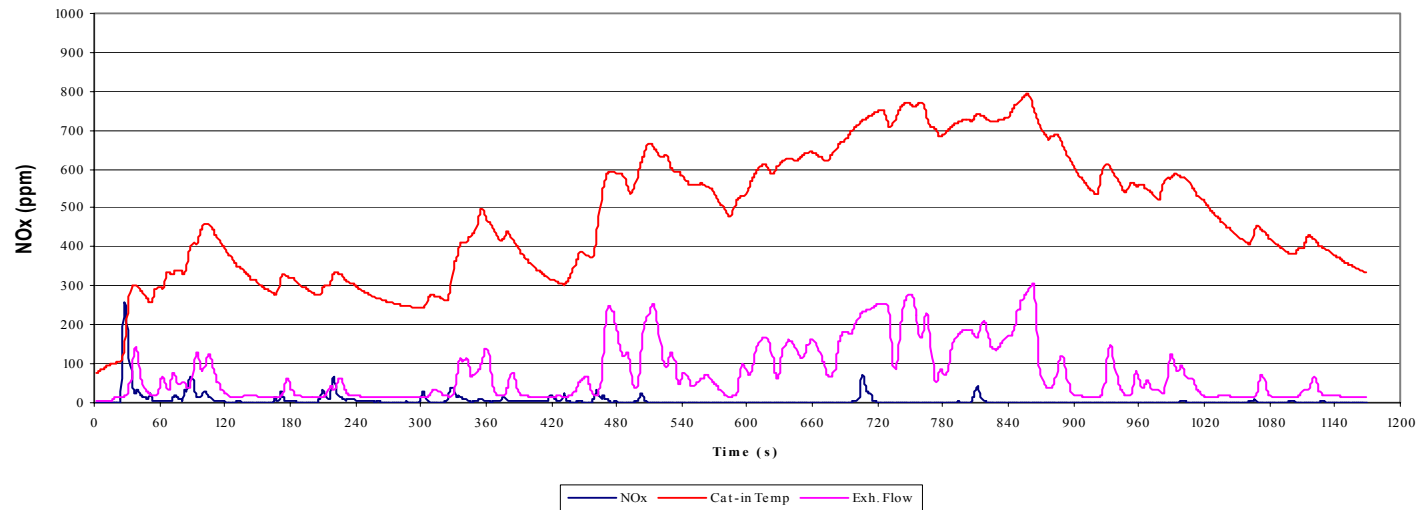
NEX Hot Transient NOx Analysis



Production Cats - Cat-out NOx, Exh. Flow, Cat-in Temp vs Time

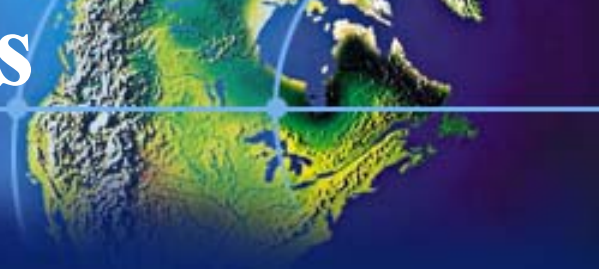


NEX Alabama Cats - Cat-out NOx, Cat-in Temp, Exhaust Flow vs Time



600 cpsi NEX Advanced Cats

Comparison with baseline



Test Description	THC g/bhp.hr	CH4 g/bhp.hr	NMHC g/bhp.hr	CO g/bhp.hr	NOx g/bhp.hr	NOx+NMHC g/bhp.hr	BSFC lbs/Hp-hr
Production Converters 125 hrs CNG hot runs average	0.36	0.345	0.015	1.04	0.202	0.217	0.413
Advanced Catalysts 125 hrs CNG hot runs average	0.101	0.095	0.006	0.931	0.08	0.086	0.414
Emissions Reductions	72%	72%	60%	11%	61%	61%	

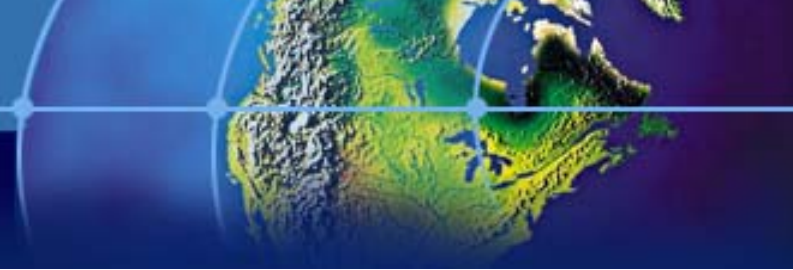
NEX Advanced Catalyst Best Performance

Useful life emissions vs Standards

Test Description	THC g/bhp.hr	NMHC g/bhp.hr	CO g/bhp.hr	NOx g/bhp.hr	NOx+NMHC g/bhp.hr	PM g/bhp.hr
Advanced Catalysts Best performance to date 125 Hr Converters CNG hot runs average	0.101	0.006	0.931	0.08	0.086	
EPA Assigned DFs	1.9	2.2	1.6	1.3		
Useful Life Emissions CNG	0.1919	0.0132	1.4896	0.104	0.1172	0.002
CARB Emissions Standards LEV II 05 SULEV			7.2		0.5	0.01
2007 and later Standfards		0.14	7.2	0.2		0.01

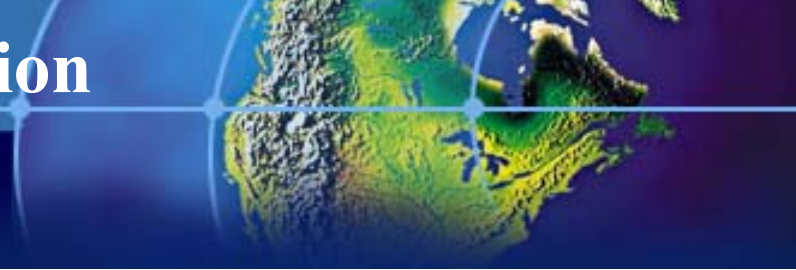
Conclusions on NGNGV

Phase I Project



- One of the advanced calibration/catalyst systems provides the opportunity for a certifiable engine package which meets the MY 07 heavy duty standards today.
- Stoichiometric engines allow entry into PZEV territory, with NO_x levels 1/20th LEV I SULEV
- NO_x emissions have been reduced 60%, and methane emissions have also been significantly reduced by 72%
- Brake specific fuel economy remains unchanged with advanced calibration/catalyst systems
- Cost impact of advanced catalyst is expected to be minimal

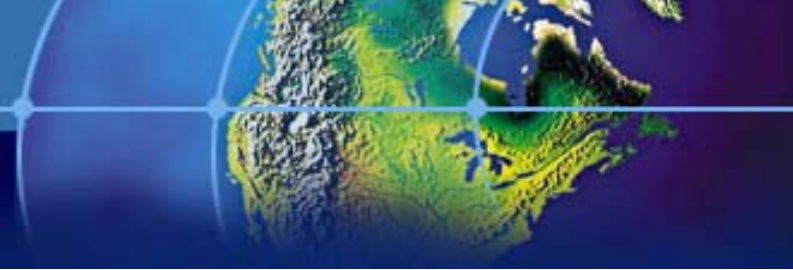
NGNGV Phase II Vehicle Integration Project Planned



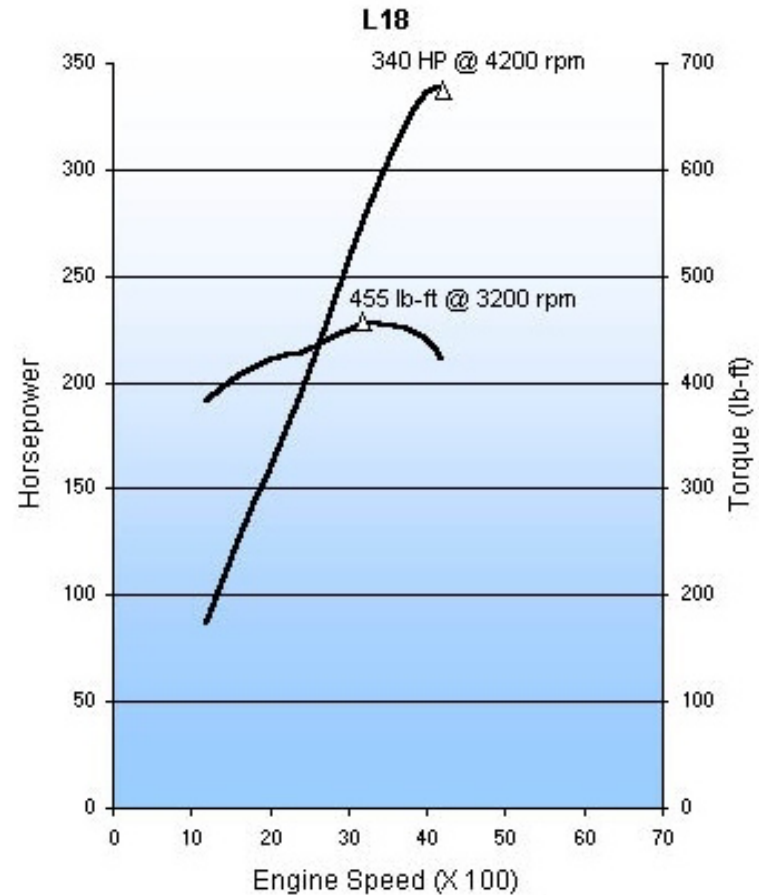
The project will involve:

- Development of a General Motors Vortec 8.1L V-8 stoichiometric S.I. CNG engine with low NOx technology
- Certification to EPA 2007 emissions standards
- Integration of the CNG engine into a low floor bus and utility truck based on the GMT 560 chassis
- Demonstration of the vehicles in fleet service including comparison with gasoline and diesel counterparts
- Customer feedback and evaluation of high potential markets
- Chassis emissions testing at West Virginia University

2004MY 8.1L Engine Details



Power – 340hp @ 4200rpm
Torque – 455ft-lb @ 3200rpm
Compression Ratio – 9.1:1
OHV Design, 2 valves/cylinder
Bore x Stroke – 107.95 x 111.00 mm



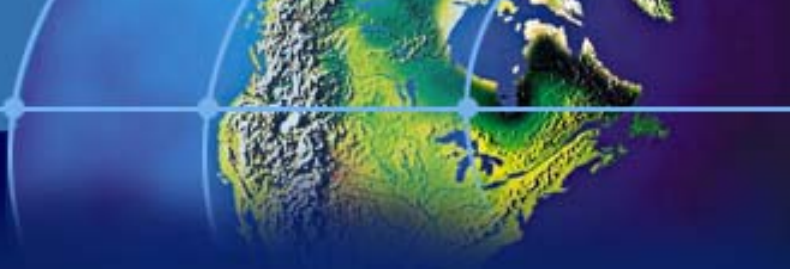
Stoichiometric CNG Engine Applications

Stoichiometric medium/heavy duty CNG engines produce low emissions, likely not attainable with advanced diesel, or even lean burn CNG engines



Typical application of GM 8.1L CNG engine

2004MY 8.1L Engine Applications



GMC Sierra 3500 Chassis Cab



Power – 287hp (est. on CNG) @ 4200rpm

Torque – 390ft-lb (est. on CNG) @ 3200rpm

Max Payload – up to 6200 lb

GVWR – up to 12000 lb

2004MY 8.1L Engine Applications

GMC C4500 / C5500 TopKick



Power – 283hp (est. on CNG) @ 4200rpm

Torque – 392ft-lb (est. on CNG) @ 3200rpm

EPA Class 4 and 5

GVWR – 16,000 to 25,950 lb

Available Chassis :

- 1-3 Passenger Regular Cab
- 1-6 Passenger Crew Cab
- Motorhome Cutaway Chassis Cab
- Commercial Cutaway Chassis Cab
- School Bus Chassis

A red Chevrolet Express box truck is shown driving on a road during sunset. The truck is angled towards the left, and the background features a warm, orange-hued sky and a distant city skyline. The truck's headlights are on, and its reflection is visible on the wet pavement.

Available Chassis : 1-3 Passenger Regular Cab
1-6 Passenger Crew Cab
Commercial Cutaway Chassis Cab

What about Fuel economy?



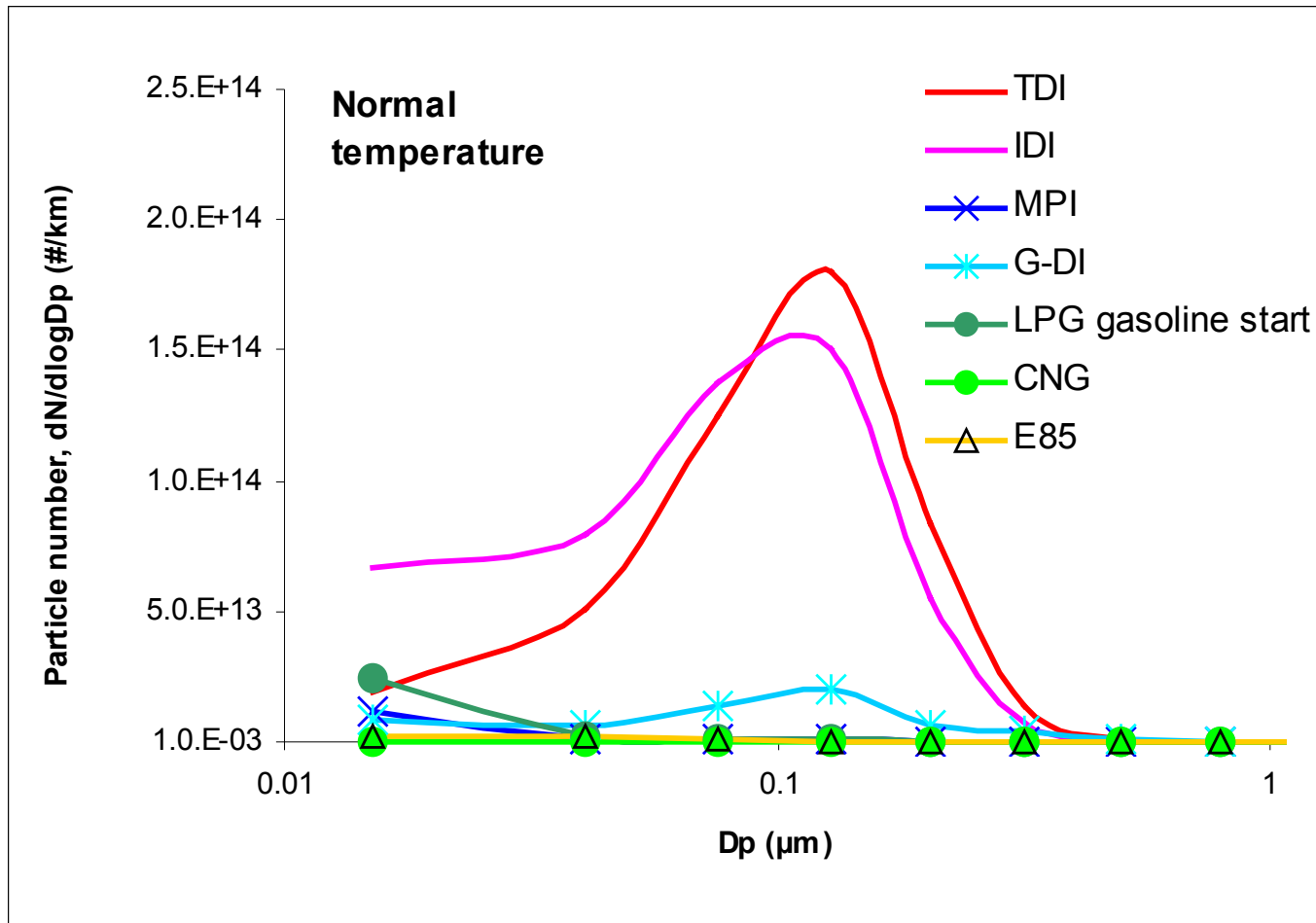
Swiss Technical Institute/IVECO, working on a stoichiometric TWC CNG engine, have shown that:

- Increasing compression ratio for efficiency improvement
- Using cooled EGR to control NO_x
- Supercharging for power/torque recovery

has resulted in engine efficiencies similar to lean burn CNG engines

Future stoichiometric CNG engines may therefore exhibit a minimal fuel economy penalty relative to lean burn engines, but have much lower emissions.

What about Particulate Number Size Distribution from Stoich. CNG Engines



Positioning of Stoich. CNG Engines Relative to Diesel, Clean Diesel and Lean Burn CNG



Vehicle Configuration	Useful Life Emissions NO _x g/bhp-hr
GM 6.0 L CNG Advanced TWC Cats	0.104
Low Emitting Diesel	3.0
Conventional Diesel	3.9
Lean Burn CNG	2.6

NO_x emissions comparison over federal FTP test cycle

CONCLUSIONS



- Medium/heavy duty stoichiometric CNG engines are capable of emissions performance today which are considerably below the EPA 2007 emissions standards
- They may be applied over a wide range of medium/heavy duty applications from Class 3 to Class 7 vehicles
- Compared with their lean burn CNG counterparts, the stoichiometric approach to medium/heavy duty CNG engines offers a clear emissions advantage over clean diesel applications today, and the fuel economy gap is likely to close with future developments
- As clean diesel emissions are reduced with aftertreatment systems this emissions advantage will decrease, but the the durability of the diesel engine system is likely to decrease, and the cost of the diesel engines in 2007 may be more expensive than the CNG counterparts, making the CNG offering more attractive to the fleet purchaser.